Delft University of Technology

Project: Geometry Learning for Complex Shaped Cells

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1 Project Description

Cells may attain various shapes and sizes, for example, stem cells can differentiate and adopt the shape and functionality of many different cell types in our body: fan-like keratocytes, hand-shaped nerve growth cones and spindle-shaped fibroblasts [2, 4]. It has been recognized that cell geometry influences cellular activities; for instance, the protrusion of the cell usually exerts larger forces than the other parts of the cell, and the cell needs to derive the protrusion (i.e. cell polarization) before it can migrate. In other words, the cell shape can also reflect the characteristics of the cell. However, in computational simulation, depicting this complex geometry requires a very fine mesh in classical methods, increasing the computational cost significantly.

Many machine learning techniques, such as classical unsupervised learning via clustering or dimension reduction (e.g. based on SVD), as well as many state-of-the-art deep learning methods are strongly based on a fixed structure of input and output data. Therefore, it is challenging to represent complex geometries as the input of many of such machine learning models. Counterexamples of models that can deal with unstructured data are, for instance, graph neural networks (GNNs) [3].

The goal of this project is to find suitable representations of complex geometries, for instance, via sampling, discretization as a mesh, or approximation of the boundary via splines, such that a machine learning model is able to extract geometrical features and predict key quantities that are of importance for the application. A suitable representation of the geometry may strongly depend on the type of machine learning model to be used; for instance, discretization as a mesh directly results in a graph, which could be used as the input for a GNN.

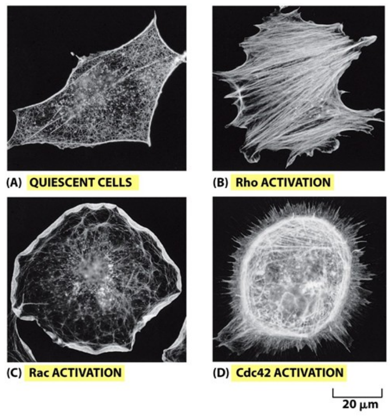

Figure 1: Cells with complex geometries observed under the microscope [1].

In this project, we will focus on the application of modeling cells in a biomedical contexts, such as how cellular forces modify the extracellular matrix (ECM), which occurs, for example, in the context of wound healing and cancer cell metastasis. This mechanical phenomenon is often modeled by the momentum balance equation (e.g., linear elasticity equation or morphoelasticity [5]). If time permits, the student is expected to apply the methodology in solving the momentum balance equation with a complicated cell shape.

Other relevant applications for this research are computer vision, industrial design etc.

Tasks

- Familiarize with a machine and deep learning software[1] to carry out this project
- Learn geometrical features from simple synthetic geometries, like circles, ellipsoids, squares, etc.
- Generate complex geometries, find suitable representations for the learning, train corresponding machine learning models, and validate the performance
- Apply to cell geometries for the application of wound healing; to compute the reference labels, numerical simulations will have to be performed

Requirements

- Expertise in machine learning and deep learning
- Basic knowledge of numerical methods for partial differential equations (e.g., FEM) for carrying out the wound healing simulations
- Programming with Python

Contact

If you are interested in this project and/or have further questions, please contact Alexander Heinlein, a.heinlein@tudelft.nl, and Qiyao Peng, q.peng@math.leidenuniv.nl.

[1]For example, PyTorch or TensorFlow

References

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